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ESTABLISHMENT OF A CRITICAL FLAW SIZE FOR THE 120-MM STUB CASE

M. D. WITHERELL

J. A. KAPP

M. A. SCAVULLO

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US ARMY ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER
CLOSE COMBAT ARMAMENTS CENTER
BENÉT LABORATORIES
WATERVLIET, N.Y. 12189-4050

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Test specimens were fabricated from 120-mm stub cases. The test specimens were used to measure mechanical properties (tensile strength, yield strength) and fracture properties (K_{Ic} and J_{Ic}). These experimental results were used in conjunction with a finite element stress analysis to calculate a critical flaw size for the 120-mm stub case. The stub case was divided into three zones and a different flaw size was established for each zone. (AW)

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TABLE OF CONTENTS

	Page
INTRODUCTION	1
EXPERIMENTAL PROCEDURES	1
STRESS ANALYSIS	3
FRACTURE MECHANICS ANALYSIS	4
DEFECT CRITERIA	5

TABLES

I.	TENSILE TEST RESULTS	2
II.	FRACTURE TOUGHNESS TEST RESULTS	3
III.	CRITICAL FLAW SIZES FOR 120-MM STUB CASE	6

LIST OF ILLUSTRATIONS

1a.	Schematic of the slow bend notched energy test.	7
1b.	Typical load deflection curve for a slow bend notched energy test.	8
2.	Schematic of 120-mm stub case showing sections and crack orientations.	9

INTRODUCTION

The 120-mm stub case is the steel rear section of a cartridge case. It provides the seal for propellant gases and is supported by the breech block. Observations have shown that defects exist on the interior surfaces of this item. The question that needs to be answered is: How long and how deep can these defects be and still not cause a catastrophic brittle failure of the case? In order to provide an answer to this question, the following steps were taken:

1. A stress analysis was conducted.
2. The fracture mechanics parameter K was determined (using the stress analysis) for various defect sizes and at various locations in the stub case.
3. Experimental determinations of K_Q were made using fracture mechanics specimens machined from available stub cases.

EXPERIMENTAL PROCEDURES

Both tensile and Charpy-sized fracture toughness specimens were manufactured from two stub cases. The stub case identifications were 434-L and 35K. The tensile specimens were taken in the longitudinal direction from the side wall of the case, and the transverse specimens were removed from the back face of the stub case as close as possible to the inner surface. The tensile specimens were 0.160-inch diameter ASTM specimens. The fracture toughness specimens were taken in only one orientation because there was only sufficient material in the back face of the case to produce this size specimen. Fracture mechanics property measurements were made at both room temperature and at -40°C, while the tensile properties were measured at room temperature only. Table I presents the results of the tensile tests. The stress versus strain curve generated by the tensile tests was used in elastic-plastic stress analysis, and the data were used to show that we have good representative material. The yield strength was also used in the fracture mechanics calculations to show that we have adequate sample size. From Table I we can observe that the material appears to have essentially similar properties in both orientations. This observation makes us more comfortable with the fact that we can only measure fracture toughness in one orientation. Figure 1 shows schematically both the loading and the load displacement trace obtained in the precracked notched slow bend test. Energy absorbed by the specimen during the test was obtained by measuring the area under the load displacement curve. The area was then used to calculate the fracture mechanics parameter, J. This toughness value can be converted to K and used to calculate maximum flaw size. Table II presents the results of the slow bend fracture toughness tests. Based on the experimental results, a K of 102 Ksi$\sqrt{in.}$ was chosen as the minimum K for the material.

TABLE I. TENSILE TEST RESULTS

Stub Case I.D.	Sample No. and Orientation	% Reduction in Area	% Elongation	0.1% Off. Yield Strength Psi	Ultimate Tensile Strength Psi
35K	1T	50.4	21.3	175,300	191,400
	2T	50.1	22.1	174,400	191,600
	3T	46.5	18.8	173,400	191,700
	1L	46.5	22.0	171,100	189,000
	2L	47.4	21.0	171,200	188,700
434-L	1T	47.4	16.5	174,900	191,800
	2T	46.5	19.1	178,200	193,600
	3T	43.8	15.9	176,000	192,700
	1L	42.8	21.5	176,600	194,100
	2L	47.4	24.8	174,700	193,500

TABLE II. FRACTURE TOUGHNESS TEST RESULTS

Stub Case I.D.	Test Temperature	Energy in.-lbs	a/W	J lbs/in.	K $Ksi\sqrt{in.}$
35K	RT	15.02	0.507	392.4	113.7
		15.21	0.507	397.3	114.4
434-L		15.28	0.523	412.3	116.6
		14.17		353.0	107.8
35K	-40°C	15.04	0.493	382.4	112.2
		14.38	0.501	371.0	110.6
434-L		22.94	0.492	582.2	138.5
		20.47	0.506	534.3	132.7

STRESS ANALYSIS

A stress analysis of the stub case was conducted using the finite element program ABAQUS. The model used in this analysis included both the stub case and the tube, as well as a clearance between the two as specified in the drawings.

Initially, an elastic analysis was done to determine stress levels in the stub case under a launch pressure of 96 Ksi. The results showed that this was not an all-compressive structure as suggested by the contractor. In fact, large magnitudes of radial and circumferential tensile stresses existed in regions of the stub case. These regions also contained levels of von Mises' stress which were significantly higher than the yield stress of the material. In actuality, these high von Mises' stresses would have to be relieved by plastic deformation. It was therefore concluded that an elastic-plastic analysis would be necessary to determine the extent of plastic flow within the stub case. The results of the elastic-plastic study showed that indeed there was fairly extensive plastic deformation, especially in region B. Also, at one point along the outside of the stub case, a residual displacement resulted which closed up 75 percent of the original clearance that existed between the stub case and the tube. It would seem quite possible that a higher firing pressure, as well as some error introduced in this analysis, could produce a residual displacement that would completely eliminate the clearance between the stub case and the tube. This result would be a potential explanation for stub cases sticking in the tube after firing a round.

FRACTURE MECHANICS ANALYSIS

As previously stated, fracture mechanics was used to determine allowable flaw sizes. This was accomplished by estimating the stress intensity factor (K) for a defective stub case under launch loading conditions. With the results from the stress analysis discussed in the previous section, all that was required was an estimate of crack sizes and geometry. We assumed that both the depth through the thickness (a) and the length of the crack (2c) could be determined. Also, we assumed that if a crack existed, it would have a semi-elliptical shape. In addition, it was assumed that the stresses in the body had a uniform tensile component (S_t) and a pure bending component (S_B).

The stress intensity factor for a semi-elliptical crack subject to both tension and bending can be given as:

$$K = \frac{\sqrt{\pi a}M}{\Phi}(S_t + HS_B) \tag{1}$$

where

$$M = \{1.13 - 0.09(a/c)\} + \{-0.54 + 0.89[0.2 + (a/c)^{-1}]\}(a/B)^2$$
$$+ \{0.5 - [0.65 + (a/c)]^{-1} + 14[1 - (a/c)]^{24}\}(a/B)^4$$

$$\Phi^2 = 1 + 1.464(a/c)^{1.65}$$

$$H = 1 - [1.22 + 0.12(a/c)](a/B) + [0.55 - 1.05(a/c)^{0.75} + 0.47(a/c)^{1.5}](a/B)^2$$

a = crack depth through the wall thickness

2c = crack length along the surface

B = the wall thickness

Using Eq. (1), we can develop the size of crack (a) and (2c) that will result in an applied K of 102 Ksi$\sqrt{\text{in.}}$ during launch.

The values of S_t and S_B for three separate sections were determined from the stress analysis discussed earlier. First, in each section, the locations of the maximum occurring tensile stress (S_{max}) were found. The minimum tensile stress (S_{min}) was that stress on the opposite side of the wall thickness. S_t and S_B can be approximated from S_{max} and S_{min} by the following relations:

$$S_B = \frac{S_{max} - S_{min}}{2} \tag{2}$$

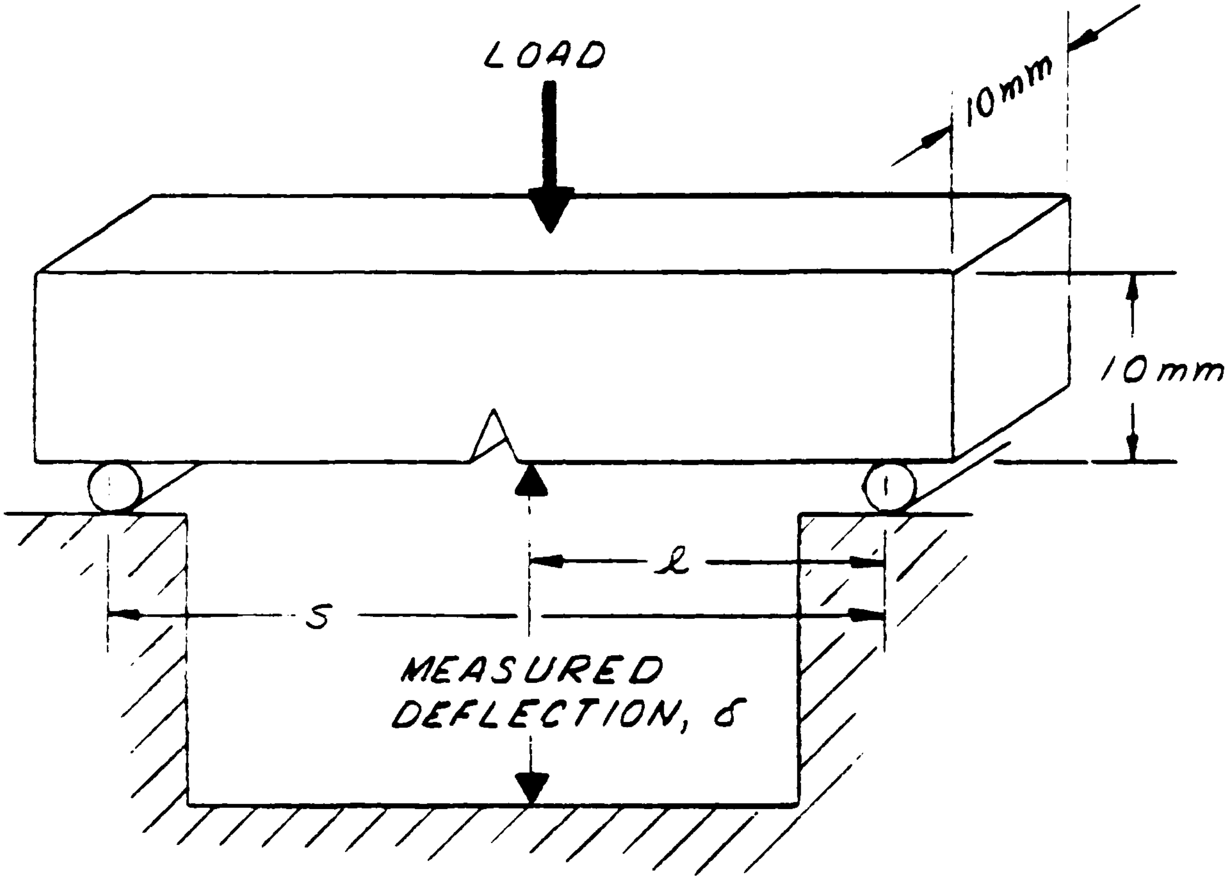
$$S_t = S_{max} - S_B \tag{3}$$

DEFECT CRITERIA

Using Eqs. (1), (2), and (3), the combination of (a) and (2c) that results in a K of 102 Ksi$\sqrt{\text{in.}}$ was determined by iteration. These results are summarized in Table III. Figure 2 is a schematic diagram showing the three sections where cracks are assumed to be located. The figure also shows the two possible directions (radial and hoop) for cracks existing in these sections.

TABLE III. CRITICAL FLAW SIZES FOR 120-MM STUB CASE

Location	Defect Orientation	S_B (Ksi)	S_t (Ksi)	a (in.)	2c (in.)
Section A	Radial	9	228	a < 0.025	3.00
				0.025	3.00
				0.050	0.44
				0.075	0.26
				0.100	0.21
				a > 0.100	0.00
Section A	Hoop	33	204	a < 0.025	13.00
				0.025	13.00
				0.050	0.51
				0.075	0.28
				0.100	0.26
				a > 0.100	0.00
Section B	Radial	2	213	a < 0.025	3.00
				0.025	3.00
				0.050	0.58
				0.075	0.29
				0.100	0.22
				a > 0.100	0.00
Section B	Hoop	62	180	a < 0.025	19.00
				0.025	19.00
				0.050	0.47
				0.075	0.29
				0.100	0.18
				a < 0.100	0.00
Section C	Radial	2	213	a < 0.025	3.00
				0.025	3.00
				0.050	0.58
				0.075	0.29
				0.100	0.22
				a > 0.100	0.00
Section C	Hoop	23	106	a < 0.050	19.00
				0.050	19.00
				0.075	7.41
				0.100	1.38
				a > 0.100	0.00



MIDPOINT DEFLECTION = $\delta S / 2\ell$

S = 1.58 INCHES FOR LONGITUDINAL

S = 1.20 INCHES FOR TRANSVERSE

Figure 1a. Schematic of the slow bend notched energy test.

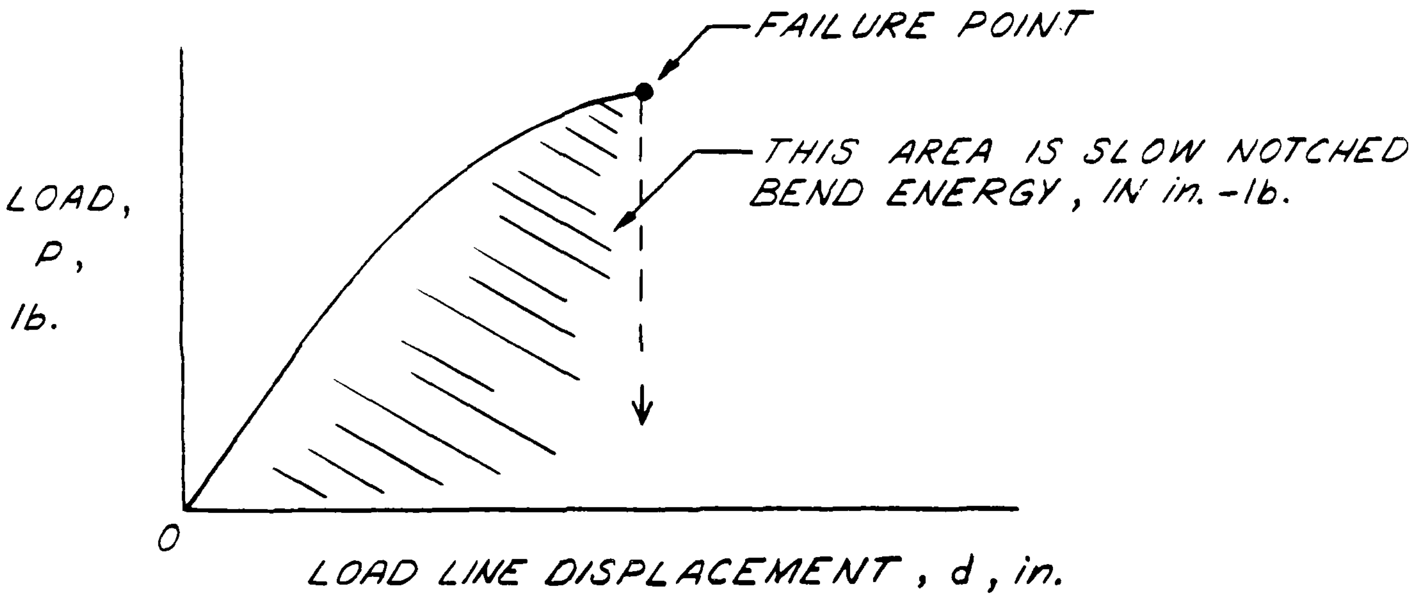


Figure 1b. Typical load deflection curve for a slow bend notched energy test.

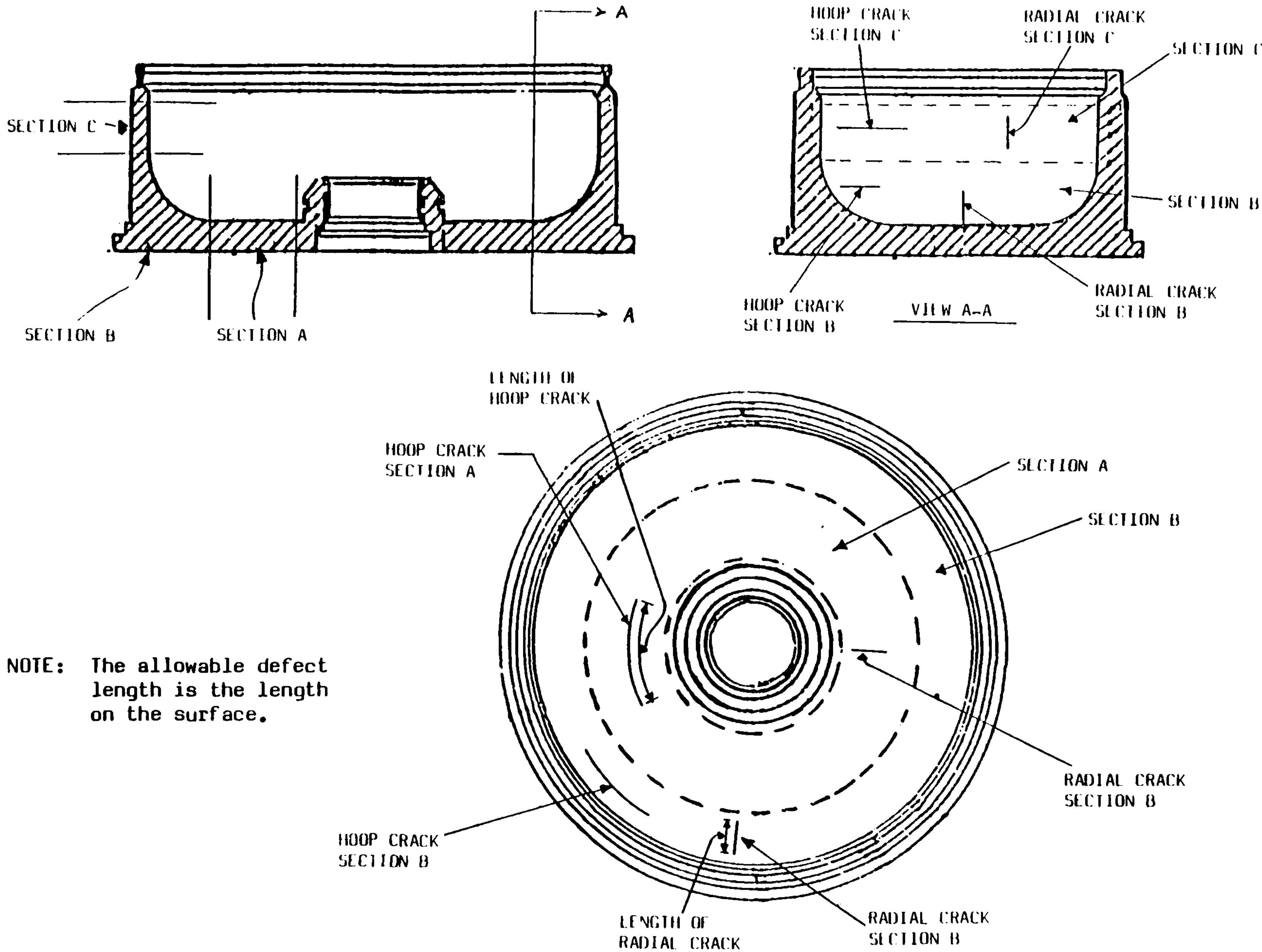


Figure 2. Schematic of 120-mm stub case showing sections and crack orientations.

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